

FRONTAL SINUS FRACTURES: CLINICAL PRESENTATION, CT-BASED INJURY PATTERNS, MANAGEMENT, AND EARLY OUTCOMES IN A RETROSPECTIVE COHORT

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Abstract

Frontal sinus fractures are rare craniofacial injuries, the management of which depends on fracture morphology, sinus drainage, posterior table integrity, and associated intracranial trauma, and through this study we evaluated clinical presentation, CT-based lesion patterns, management strategies, and early outcomes in a retrospective cohort. We followed 43 consecutive adult patients with CT-confirmed frontal sinus fractures, who were managed in a specialized outpatient clinic between January 2021 and December 2025. We analyzed demographic, clinical, radiological, treatment and follow-up data and associations with surgical management have been explored using chi-square tests or Fisher's exact tests and unadjusted odds ratios. Twenty-seven patients (62.8%) were managed conservatively and 16 (37.2%) were managed surgically. Operative treatment was more common in displaced, comminuted, posterior mass fractures, escape routes and associated with pneumocephaly. Seven patients (16.3%) developed at least one complication, and two required additional intervention. No meningitis, intracranial abscess or mortality occurred. These findings support selective intervention rather than routine operative management. Most of the frontal sinus fractures observed by us were successfully managed conservatively, while surgery was reserved for more serious radiological injuries, and CT-based assessment, individualized treatment selection, and structured patient follow-up remain essential for limiting functional, infectious, neurological, and aesthetic sequences.

Keywords: frontal sinus fracture, computed tomography, surgical management, conservative treatment, craniofacial trauma, clinical outcomes.

Introduction

Frontal sinus fractures are uncommon but clinically important injuries because they may involve the anterior or posterior sinus table, the frontal sinus outflow tract, the orbit, the dura, and intracranial structures, and management must therefore restore frontal contour, preserve sinus function when possible, and reduce the risk of cerebrospinal fluid leakage, infection, mucocele formation, and neurological complications, and current evidence supports an individualized approach based on fracture morphology, displacement, associated injuries, and sinus drainage status [1-4]. Comparisons between open and endoscopic techniques have also shown that no single treatment strategy is appropriate for all fracture patterns [2].

Computed tomography is essential for diagnosis and treatment planning because it allows assessment of table involvement, comminution, displacement, pneumocephalus, outflow tract injury, and associated craniofacial trauma [3,4]. Conservative management is generally considered appropriate for selected nondisplaced fractures without major posterior table disruption or persistent cerebrospinal fluid leakage [4]. However, frontal sinus injuries frequently coexist with orbital and ocular trauma [5] and are often part of more complex craniofacial injury patterns [6]. The development of endoscopic techniques has increased the possibility of sinus-preserving and minimally invasive treatment [2,7], although considerable variation remains between institutions regarding observation, fixation, obliteration, and cranialization [8-10].

Several management algorithms have attempted to integrate displacement, posterior table integrity, outflow tract involvement, cerebrospinal fluid leakage, and intracranial injury into clinical decision-making [9]. Recent evidence suggests that selected outflow tract fractures may be treated conservatively when close clinical and radiological follow-up is available [10]. Nevertheless, inadequate initial assessment may result in delayed frontal contour deformity, chronic sinus dysfunction, infection, or secondary reconstructive requirements [11].

Recent retrospective cohorts have reported that displacement, comminution, posterior table involvement, dural injury, and cerebrospinal fluid leakage are more frequently associated with surgical treatment [12]. Differences in injury mechanism, fracture classification, and management patterns have also been observed among trauma populations [13,14]. In selected anterior table fractures, minimally invasive reduction may provide satisfactory aesthetic results [3,14], whereas obliteration or cranialization remains necessary in more severe injuries when sinus preservation is unsafe [15].

Against this background, we conducted the present study to describe the clinical presentation, CT-based injury patterns, management strategies, and early outcomes of frontal sinus fractures in a consecutive retrospective cohort of 43 patients. Our study also explored the clinical and radiological characteristics associated with surgical management.

Materials and Methods

Study design

This study of ours, which is retrospective observational cohort, included consecutive patients with CT-confirmed frontal sinus fractures managed in a specialized outpatient clinic between January 2021 and December 2025, and clinical records, CT scans, treatment documentation, operative reports, and follow-up data were reviewed using a standardized data collection form.

Our study evaluated clinical presentation, CT-based fracture patterns, management strategies, and early outcomes, and the primary analysis explored the association between selected clinical and radiological features and surgical management.

Patient selection and clinical variables

Patients 18 years of age or older were included if they had a CT-confirmed traumatic frontal sinus fracture and complete clinical, radiological, treatment, and follow-up information, and pathological or previously treated fractures, unavailable or inadequate CT scans, and incomplete records were excluded, and the final cohort comprised 43 patients, and the variables recorded included age, sex, mechanism of injury, loss of consciousness, traumatic brain injury, frontal soft tissue cutting, cerebrospinal fluid leakage, associated craniofacial fractures, duration of hospitalization, and duration of follow-up. Injury mechanisms have been classified as road accidents, falls, interpersonal violence, occupational accidents or sports trauma.

CT-based fracture assessment

All computed tomography examinations were independently reviewed by two investigators with experience in craniofacial trauma: one oral and maxillofacial surgeon and one

radiologist. The recorded radiological variables included anterior table involvement, posterior table involvement, combined fracture pattern, displacement, comminution, frontal sinus outflow tract involvement, hemosinus, pneumocephalus, intracranial injury, orbital fracture, and naso-orbito-ethmoidal fracture, and frontal sinus outflow tract involvement was considered present when the fracture extended into the inferomedial frontal sinus, frontal recess, or nasofrontal drainage region.

Disagreements between the two reviewers were resolved by joint reassessment and consensus. When consensus could not be reached, a third senior investigator reviewed the examination and provided the final classification. Interobserver agreement was assessed using Cohen's kappa coefficient for the principal categorical CT variables.

Management and outcome assessment

We classified management as conservative or surgical, and conservative management included observation, neurological monitoring, sinus precautions, symptomatic treatment, and follow-up imaging when necessary, also surgical treatment included open reduction and internal fixation, frontal sinus obliteration, cranialization, or combined craniofacial reconstruction.

The primary outcome was the use of surgical treatment, and the secondary outcomes were complications, further interventions, meningitis, intracranial abscess, persistent neurological damage, and mortality, and documented complications included irregularity of the frontal contour, persistent frontal hypophysis, superficial wound infection, and persistent cerebrospinal fluid leakage.

Statistical analysis

We performed the statistical analysis using the GraphPad Prism software, with version 10.2.3 (GraphPad Software, Boston, MA, USA), and we reported the continuous variables as mean and standard or median deviation and the interquartile range, while the categorical variables were presented as frequencies and percentages.

Associations between surgical management and displacement, compression, posterior mass involvement, frontal outflow sinus tract involvement, pneumocephaly, cerebrospinal fluid leakage, and intracranial injury were assessed using the chi-square test or the Fisher's exact test, and unadjusted odds ratios with 95% confidence intervals were calculated.

Interobserver agreement for CT-based main fracture features was assessed using Cohen's kappa coefficient. The kappa values below 0.40 were interpreted as weak to correct agreement, the values between 0.40 and 0.60 as moderate agreement, the values between 0.61 and 0.80 as substantial agreement, and the values above 0.80 as almost perfect agreement, and the statistical significance was established at $p < 0.05$, and due to the limited number of surgical cases we considered the analyses exploratory and did not make a multivariate model.

Results

Demographic and trauma-related characteristics

A total of 43 patients with CT-confirmed frontal sinus fractures were included in the retrospective cohort, and our study population consisted of 32 males (74.4%) and 11 females (25.6%), with a mean age of 38.7 ± 15.6 years, and the majority of patients were adults of working age, although the cohort included individuals from early adulthood to old age.

Road traffic accidents represented the most frequent mechanism of injury, accounting for 18 cases (41.9%), and falls were identified in 11 patients (25.6%), followed by interpersonal violence in seven cases (16.3%), occupational accidents in four cases (9.3%), and sports-related trauma in three cases (7.0%). The distribution of traumatic mechanisms is illustrated in Figure 1.

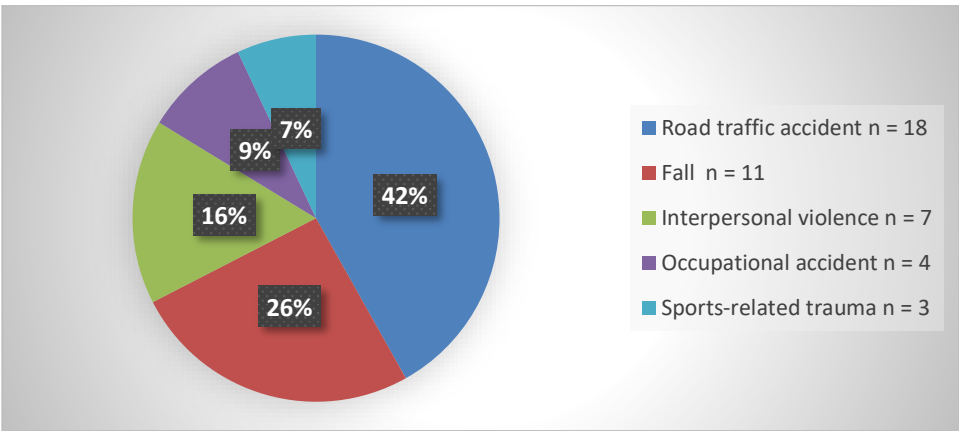


Figure 1. Distribution of injury mechanisms among patients with frontal sinus fractures. Values represent the percentage of the total our study population.

Loss of consciousness at the time of injury was documented in 14 patients (32.6%), while 17 patients (39.5%) had an associated traumatic brain injury. A frontal soft-tissue laceration was present in 19 cases (44.2%). Cerebrospinal fluid leakage was identified in five patients (11.6%), and associated craniofacial fractures were observed in 29 patients (67.4%). The demographic and trauma-related characteristics of the cohort are summarized in Table 1.

Table 1. Demographic, clinical, and trauma-related characteristics of the our study population.

Variable	Category or summary measure	n (%) or value
Total sample	Patients included	43
Age, years	Mean ± SD	38.7 ± 15.6
Sex	Male	32 (74.4)
	Female	11 (25.6)
Mechanism of injury	Road traffic accident	18 (41.9)
	Fall	11 (25.6)
	Interpersonal violence	7 (16.3)
	Occupational accident	4 (9.3)
	Sports-related trauma	3 (7.0)
Loss of consciousness	Present	14 (32.6)
Traumatic brain injury	Present	17 (39.5)
Frontal soft-tissue laceration	Present	19 (44.2)
Cerebrospinal fluid leakage	Present	5 (11.6)
Associated craniofacial fracture	Present	29 (67.4)
Length of hospitalization, days	Median (IQR)	5 (3–8)

CT-based fracture patterns

Fractures limited to the anterior table of the frontal sinus were identified in 20 patients (46.5%). Isolated posterior table fractures were uncommon, occurring in 4 cases (9.3%), whereas combined anterior and posterior table involvement was present in 19 patients (44.2%).

Twenty-eight fractures (65.1%) were displaced, and 22 (51.2%) were comminuted. Frontal sinus outflow tract involvement was suspected on CT in 14 patients (32.6%). Hemosinus was the most frequent radiological finding, being present in 37 cases (86.0%). Pneumocephalus was identified in 10 patients (23.3%), and 12 patients (27.9%) had an associated intracranial injury.

Orbital fractures accompanied the frontal sinus injury in 18 patients (41.9%), while nine patients (20.9%) had associated naso-orbito-ethmoidal fractures. The complete distribution of CT-based injury characteristics is presented in Table 2.

Table 2. CT-based characteristics of frontal sinus fractures

Radiological characteristic	n	%
Anterior table fracture only	20	46.5
Posterior table fracture only	4	9.3
Combined anterior and posterior table fracture	19	44.2
Displaced fracture	28	65.1
Comminuted fracture	22	51.2
Frontal sinus outflow tract involvement	14	32.6
Hemosinus	37	86.0
Pneumocephalus	10	23.3
Intracranial injury	12	27.9
Associated orbital fracture	18	41.9
Associated naso-orbito-ethmoidal fracture	9	20.9

The relationship between the principal CT-based fracture patterns and treatment strategy is shown in Figure 2, and surgical management was used most frequently in patients with frontal sinus outflow tract involvement, posterior table fractures, and comminuted or displaced injuries.

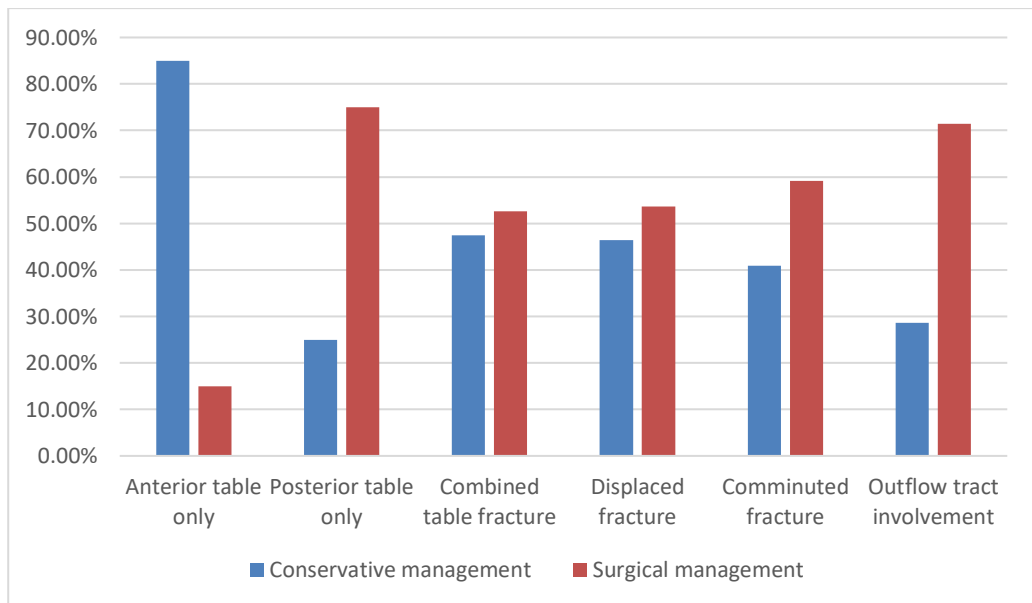


Figure 2. Distribution of conservative and surgical management according to the principal CT-based fracture characteristics. Percentages were calculated within each radiological category.

Management and early outcomes

Twenty-seven patients (62.8%) were followed conservatively, while 16 patients (37.2%) underwent surgical treatment, as shown in Figure 2, operative management was used more

frequently in patients with posterior mass involvement, displacement, comminution, and frontal sinus outflow tract injuries.

Among surgically treated patients, open reduction and internal fixation was the most frequently performed procedure, followed by cranialization, frontal sinus obliteration, and combined craniofacial reconstruction, and during follow-up, seven patients (16.3%) developed at least one complication, and two patients (4.7%) required an additional intervention. No cases of meningitis, intracranial abscess, or mortality were recorded. Management strategies and early outcomes are summarized in Table 3.

Table 3. Management strategies and early outcomes in patients with frontal sinus fractures

Variable	Category	n	%
Management strategy	Conservative management	27	62.8
	Surgical management	16	37.2
Surgical procedure*	Open reduction and internal fixation	8	50.0
	Frontal sinus obliteration	3	18.8
	Cranialization	4	25.0
	Combined craniofacial reconstruction	1	6.3
Patients with at least one complication	Present	7	16.3
Documented complication	Residual frontal contour irregularity	3	7.0
	Persistent frontal hypoesthesia	2	4.7
	Superficial wound infection	1	2.3
	Persistent cerebrospinal fluid leakage	1	2.3
Additional intervention required	Yes	2	4.7
Meningitis	Present	0	0.0
Intracranial abscess	Present	0	0.0
Mortality	Present	0	0.0
Follow-up duration, months	Median (IQR)	6 (3–11)	—

*Percentages for surgical procedures were calculated using the 16 surgically treated patients as the denominator, and percentages for complications and other outcomes were calculated using the total cohort of 43 patients.

Factors Associated with Surgical Management

Displaced fractures were treated surgically in 15 of 28 cases (53.6%), compared with one of 15 non-displaced fractures, and displacement was therefore strongly associated with operative management in the unadjusted analysis.

Comminution, posterior table involvement, frontal sinus outflow tract involvement, and pneumocephalus were also significantly more frequent among surgically managed patients. Cerebrospinal fluid leakage showed a numerical association with surgical treatment, although statistical significance was not reached, likely because only 5 patients had this finding.

Associated intracranial injury was more frequent among surgically treated patients, but the difference did not reach statistical significance, and given the limited cohort size and the number of operative cases, all associations were considered exploratory and were not entered into a multivariable regression model. The unadjusted analyses are presented in Table 4.

Table 4. Unadjusted exploratory associations between clinical or radiological characteristics and surgical management

Variable	Surgical n/N (%)	Conservative n/N (%)	Unadjusted OR (95% CI)	p-value
Displaced fracture	15/28 (53.6)	13/28 (46.4)	16.15 (1.86–140.14)	0.003
Non-displaced fracture	1/15 (6.7)	14/15 (93.3)	Reference	—
Comminuted fracture	13/22 (59.1)	9/22 (40.9)	8.67 (1.96–38.41)	0.004
Non-comminuted fracture	3/21 (14.3)	18/21 (85.7)	Reference	—
Posterior table involvement	13/23 (56.5)	10/23 (43.5)	7.37 (1.68–32.32)	0.010
No posterior table involvement	3/20 (15.0)	17/20 (85.0)	Reference	—
Outflow tract involvement	10/14 (71.4)	4/14 (28.6)	9.58 (2.21–41.55)	0.002
No outflow tract involvement	6/29 (20.7)	23/29 (79.3)	Reference	—
Pneumocephalus	7/10 (70.0)	3/10 (30.0)	6.22 (1.31–29.45)	0.024
No pneumocephalus	9/33 (27.3)	24/33 (72.7)	Reference	—
Cerebrospinal fluid leakage	4/5 (80.0)	1/5 (20.0)	8.67 (0.87–86.07)	0.056
No cerebrospinal fluid leakage	12/38 (31.6)	26/38 (68.4)	Reference	—
Intracranial injury	7/12 (58.3)	5/12 (41.7)	3.42 (0.86–13.67)	0.092
No intracranial injury	9/31 (29.0)	22/31 (71.0)	Reference	—

Overall, the findings indicated that surgical management was primarily associated with radiological markers of greater injury severity, particularly fracture displacement, comminution, posterior table involvement, and compromise of the frontal sinus outflow tract.

Discussion

Through this study we evaluated clinical presentation, CT-based injury patterns, management strategies, and early outcomes of frontal sinus fractures in a retrospective cohort of 43 patients. Our main finding was that surgical management was predominantly used in fractures of greater radiological severity, especially displacement, compression, posterior mass involvement, and compromise of the frontal sinus outflow tract, and most patients were nevertheless managed conservatively, indicating that observation remains appropriate when the anatomical integrity and drainage of the sinuses are sufficiently preserved.

The distribution of treatment in our cohort is consistent with contemporary evidence supporting selective rather than routine surgical intervention, and systematic reviews have shown that treatment decisions should integrate fracture morphology, posterior table status, cerebrospinal fluid leakage, and outflow tract function rather than rely solely on the presence of a frontal sinus fracture [1,4]. The growing role of endoscopic and sinus-preserving approaches has further reduced the need for extensive procedures in carefully selected patients [2,7]. Our findings, therefore, support a management strategy based on CT-defined injury severity and associated clinical features.

The association between operative treatment and fracture displacement or comminution was as expected clinically, and displaced anterior table fractures may produce persistent contour deformity, whereas severe posterior table disruption may increase the risk of intracranial communication and infectious complications [3,8]. Similar retrospective studies have identified displacement, posterior table involvement, dural injury, and cerebrospinal fluid leakage as characteristics frequently associated with surgical management [9,12]. In our cohort, suspected outflow tract involvement was also strongly related to operative treatment, and although selected outflow tract fractures can be managed conservatively, this approach requires reliable clinical and radiological follow-up, as persistent obstruction may lead to delayed sinus dysfunction or mucocele formation [10].

Open reduction and internal fixation was the most frequently performed operation in our study, reflecting the predominance of injuries requiring restoration of the frontal contour, and obliteration and cranialization were reserved for more complex fractures in which sinus preservation was considered unsafe, and this distribution is comparable with contemporary trauma-center experience and recent surgical series [6,15]. Less invasive reduction may remain suitable for selected anterior table fractures, particularly when displacement is limited and posterior structures are intact [14-17].

Early complications were uncommon and mainly included contour irregularity, frontal hypoesthesia, wound infection, and persistent cerebrospinal fluid leakage, and these outcomes emphasize the need for follow-up because secondary deformity and sinus-related complications may become clinically apparent after the initial treatment period and the absence of meningitis, intracranial abscess, and mortality in our cohort is reassuring but should be interpreted cautiously given the limited sample size [11].

Our study has several limitations, and its retrospective, single-center design may introduce selection and information bias, while the small cohort limited statistical power and precluded multivariable analysis, and follow-up duration was also variable, and late complications may have been underestimated. Nevertheless, our article provides a clinically relevant overview of frontal sinus trauma managed in a specialized outpatient setting and supports CT-based, individualized decision-making.

Conclusions

Most frontal sinus fractures in this cohort were managed conservatively, and surgical treatment was more frequently selected for displaced, comminuted, posterior table, and frontal sinus outflow tract fractures. Because of the small sample size and relatively short follow-up, these associations should be regarded as exploratory and require confirmation in larger multicenter cohorts.

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Received: February 20, 2026

Accepted: May 27, 2026